FINAL REPORT

Sodium-Metal-Halide Battery Energy Storage for DoD Installations

ESTCP Project EW-201246

OCTOBER 2017

Dan Cohee
PDE Total Energy Solutions

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Dynapower LLC provided valuable inputs, guidance and access to their facilities.

14. ABSTRACT
The primary objective of this program is to demonstrate and assess the energy security, energy efficiency and reliability benefits realized from the integration of a 1MVA, 576kWhr, Battery Energy Storage System (BESS) that works in concert with DoD Project EW-200937 micro-grid controls at the Twentynine Palms Marine Core Base. The project will demonstrate how a robust BESS will alleviate renewable energy intermittency, improve island-mode operations, reduce demand charges and peak load stress on the main transformers and other grid equipment. Twentynine Palms currently requires the use of load shedding to avoid overload of the sub-station during high demand periods, in grid-tied mode. Twentynine Palms micro-grid operating in island mode has two restrictions, (a) poor power factor of the site loads resulting in co-generation facility operation at reduced real power levels; (b) inability to accept the contribution of the significant PV resources in micro-grid mode. The proposed BESS project will utilize advanced control algorithms to address these issues.

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ACRONYMS AND ABBREVIATIONS

BESS	Battery Energy Storage System, a collection of components which interface battery energy storage to the electrical network.
DoD	Department of Defense
GE	General Electric (company)
LCOE	Levelized Cost of Energy (exchanged by a battery)
MCAGCC	Marine Corps Air Ground Combat Center
MV	Medium Voltage, distribution circuits in the range of 1~ 69 kV
PCS	Power Conditioning System, electrical equipment for AC interface
PDE	Pacific Data Electric
V&F	Voltage and Frequency, power quality measurements
VA	Volt-Amp, units for apparent power
VAr or VAR	Volt-Amp Reactive, reactive power flow, either leading or lagging.
W	Watts, units for real power

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The authors want to thank the Public Works Department at the MCAGCC 29 Palms for sponsoring this project and for all the time spent on the project.

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EXECUTIVE SUMMARY

This project had a goal of demonstrating and assess the energy security, energy efficiency and reliability benefits realized from the integration of a 1 MVA, 250kW, 576 kWh, Battery Energy Storage System (BESS) at a US DoD base of operations. This BESS unit was based upon the Sodium Metal Halide technology which was being produced in Schenectady, NY by the General Electric Company.

The team lead by PDE Total Energy Solutions (PDE), designed, built, and tested the BESS at the Dynapower facility in Burlington, VT. The BESS unit was then shipped to the Marine Corp Air-Ground Combat Center (MCAGCC) at Twentynine Palms, CA, where it awaited installation. The installation at the base was delayed several times due to panel failures in the solar field and due to other infrastructure upgrade projects, some of which also required utility interconnection agreements. During this time, the base's preference was to bundle the submission of interconnect agreements.

A mutual decision was made by ESTCP, MCAGCC and PDE to pre-maturely terminate this project before the final demonstration. The reasoning was:

- Failure of the Sodium-Metal-Halide technology's ability to succeed in the marketplace, and its subsequent termination as a public product offering, after 4 years of production.
- Concerns that the prototype BESS unit could not be operated by other entities due to its status as an experimental prototype, which had product liability concerns.
- Changes in the infrastructure at the MCAGCC which reduced the benefit and impact of the proposed BESS.

OBJECTIVE OF THE DEMONSTRATION

The objectives of the demonstration program were:

1. Co-Gen Power Factor Improvement; to improve the efficiency of the main co-generation plant by providing reactive power support with the BESS.
2. Peak Shave Functionality (and economic benefit) to reduce the monthly electricity demand charge by reducing the peak power draw via BESS discharge during the peak hours.
3. Renewable Energy Smoothing 1 (grid tied), to assist with renewable power intermittency by dispatching the BESS power.
4. Renewable Energy Smoothing 2 (grid independent), to help leverage more renewable energy during grid independent mode, by dispatching the BESS to smooth the power profile and ensure frequency and voltage stability.
5. Durathon™ Battery Bank Availability, monitoring the reliability of the BESS

TECHNOLOGY

The key technology being demonstrated was the Sodium Metal-Halide battery system, which was marketed by GE as the Durathon™ product line. This battery technology featured robust packaging that was insensitive to ambient temperatures, it had benign failure modes, and long cycle life. The major limitation on the technology was the pricing and performance was not competitive with recent developments in Lithium-ion based solutions. There were only two manufactures of the Sodium Metal-Halide (also known as Sodium-Nickel Chloride)

DEMONSTRATION RESULTS

The performance of the system was never evaluated at the DoD base, but the technology was tested at the Dynapower facility in Burlington, VT before shipment to base. Most of the operating modes were verified prior to shipment to the MCAGCC.

The effectiveness of the BESS to meet the objectives are summarized here.

- The Sodium-Metal-Halide technology could operate at extreme ambient temperatures, but the early prototypes did struggle with managing sand ingress.
- The Sodium-Metal-Halide technology was not successful in the marketplace and was overcome by competition from multiple vendors and developers of Li-Ion technology, hence it was terminated as a product offering.
- Calculations show that a BESS unit can technically address the functions of peak power shaving, renewable smoothing, and power factor assistance, but there is little to no financial benefit for serving these during normal grid tied operation. This is due to either the lack of financial incentives, or dis-incentives, or a tradeoff between losses in the network vs. losses in the BESS.
- Demonstrate how a BESS could assist DoD installations during microgrid island operations to achieve more energy surety.

IMPLEMENTATION ISSUES

No transition or future implementation of the technology will occur due GE no longer supporting the battery technology.

The inverter was specifically designed for the Durathon prototype battery used on this project and it has been determined the cost to reconfigure the unit is more costly than procuring a new unit. The inverter will be removed from site and trucked to a government facility for scrapping or redeployment.

The Durathon battery will also be removed from site and trucked to a government facility. It was determined that the batteries were not warranted, nor did support from GE existing to energize the battery. It is in PDE"s opinion the batteries should be recycled due to lack of appropriate personnel who need to perform pre-energization safety checks and procedures.

The Microgrid controller GE was to integrate to the U90 has also been abandoned in lieu of a new control system, thus all control equipment onsite will be turned over to the base personnel.

It should be noted that when installing experimental equipment on an active base the following challenges were encountered:

- Timely submission of utility interconnect agreement due to competing projects and base decision to submit the BESS interconnect with the new co-gen plant that was installed. Had this not been a hurdle the technology could have been tested.
- Change in MCAGCC 29 Palms project management personnel caused a restart of the project three times. New personnel required time to familiarize themselves with the project prior to being able to implement construction and processes required to energize the BESS.
- Delays caused additional costs for both PDE and GE requiring contract amendments.

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1.0 INTRODUCTION

This project had a goal of demonstrating and assessing the energy security, energy efficiency and reliability benefits realized from the integration of a 1 MVA, 250kW, 576 kWhr, Battery Energy Storage System (BESS) at a US DoD base of operations. This BESS unit was based upon the Sodium Metal Halide technology which was being produced in Schenectady, NY by the General Electric Company.

1.1 BACKGROUND

The BESS technology had the opportunity to address the challenges of integrating intermittent renewable energy to a microgrid. The BESS would act as the ramp rate control between both the generation and the solar allowing seamless operation while islanded from the local grid. This will allow clean energy to remain online during islanded operation and reduce the amount of fuel consumed by the co-generation plant.

The market for BESS installations on the electricity grid matured over the years of the project.

Sodium-metal-halide technology did not achieve market success due to the rapid improvements in Lithium-ion technology from adjacent markets (consumer electronics, and automotive) which lead to technology and price improvements. GE stopped production of the Durathon™ product line in 2015.

1.2 OBJECTIVE OF THE DEMONSTRATION

The project had a primary objective of how a BESS could benefit a typical military base:

1. Co-Gen Power Factor Improvement; to improve the efficiency of the main co-generation plant by providing reactive power support with the BESS.

2. Peak Shave Functionality (and economic benefit) to reduce the monthly electricity demand charge by reducing the peak power draw via BESS discharge during the peak hours.

3. Renewable Energy Smoothing 1 (grid tied), to assist with renewable power intermittency by dispatching the BESS power.

4. Renewable Energy Smoothing 2 (grid independent), to help leverage more renewable energy during grid independent mode, by dispatching the BESS to smooth the power profile and ensure frequency and voltage stability.

The project had a secondary objective of how Sodium-Metal-Halide technology performed in meeting the BESS functions

5. Durathon™ Battery Bank Availability, monitoring the reliability of the BESS.

1.3 REGULATORY DRIVERS

The drivers for operating a BESS at a DoD base come from concerns for energy security and energy cost reductions. Future time of use tariff rates will also drive the economic feasibility for BESS systems at DOD installations as demand charges will shift to hours when no solar is being produced, requiring batteries to be dispatched during evening hours.

2.0 TECHNOLOGY DESCRIPTION

The core technology demonstration for this project is discussed in the following sub-sections.

2.1 TECHNOLOGY OVERVIEW

The core technology under evaluation for the proposed effort was the Sodium-Metal-Halide energy storage system, shown in Figure 1.

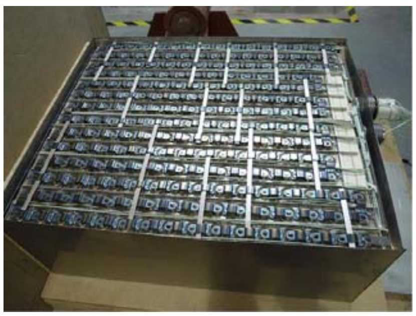
a)  b) 

Figure 1. Sodium Metal Halide Battery Technology

a) open battery module with cover removed, b) enclosure with multiple battery modules.

This battery technology was proposed because it represented a robust, high temperature technology that was less volatile and less environmentally sensitive than lithium-ion.

Other, secondary technologies that were integrated into the BESS were the Power Conversion System (PCS), and the BESS dispatch controls to achieve the desired functionality with the electrical network.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

This project had two levels of technology demonstration. The first was the use of a BESS to help improve electrical operations at a base of operations, the second level of technology demonstration was the use of Sodium-Metal-Halide technology within the BESS unit.

The key advantages of the sodium-metal-halide battery included the following:

- robust battery packaging which included a thermally insulated enclosure, allowing for wide ambient temperature ratings (-40*C to +60*C), and no need for air conditioning
- benign cell failure modes which did not result in thermal cascade failures, or violent outburst of energy.
- low raw material costs which were predicted to result in low battery pricing once high production volumes were achieved.

Table 1. Comparison of Various Technologies (2014 projections)

Technology	Main advantage	Main Disadvantage	Cost ($/kWh) [1]
Na-NiCl2	Robust packaging, insensitive to ambient temperature, benign failure modes	Two suppliers globally, specialized manufacturing methods	350-400
Li-Ion	Development driven by high volume markets, Growing global supply base	Violent failure modes, Less confident cycle & calendar life	500-600
Lead Acid	Availability, mature suppliers	Low cycle life and need for temperature control	80~100
Na-Sulfur	Robust packaging, insensitive to ambient temperature	Challenging failure modes, one supplier, designed for slow rate operation (4-7 hours)	350-450

[1] Projected market pricing for BESS integrators in CY 2014

3.0 PERFORMANCE OBJECTIVES

The Performance Objectives for the project matured from the proposal stage to the development stage. The summary of Performance objectives are summarized in the below table.

Table 2. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Grid Tied Operations				
1. Improve power factor	Measure improvement in Co-gen pf	Power meter measurements	Higher power factors	VAr dispatch tested
2. Peak Shave Functionality	Reduction in daily peak power consumption	Power meter measurements	Measurable drop in 15-min peak power	Not tested
3. PV smoothing	Measure improvement in power quality	Power meter measurements	Power quality improvements	15-min averaging and 5-hour averaging tested
Island Mode Operation				
4. PV smoothing	Ability to operate island mode with PV contributing (not disconnected)	Power meter measurements (Voltage, Frequency, Power)	Operation in island mode with PV contributing	Not tested

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4.0 FACILITY/SITE DESCRIPTION

The program planned on demonstrating the BESS technology at the MCAGCC at Twentynine Palms in California. The BESS was to be directly connected to the existing microgrid via circuit 7 on substation "AA".

4.1 FACILITY/SITE LOCATION AND OPERATIONS

The objective of the demonstration at a DoD installation site was to further validate, refine, and transition the technologies to commercialization. The on-site testing was perceived to allow the developers to collect real-time data and feedback, and identify gaps and shortfalls for further improvement and next generation design. It was also done to give users first-hand experience in using and interfacing with the new technology and product. PDE had worked with the DoD assigned liaison in selecting the site for demonstration. A subset of the criteria used for site selection included:

- Government furnished equipment
- DG resources (solar PV, diesel Genset, fuel cell and combined heat and power/CHP)
- Availability or plan for energy storage
- Acceptance and participation in smart grid technology
- Controllable building loads such as HVAC and chiller
- Electricity cost and plans to incorporate variable electricity pricing
- Advanced metering infrastructure and Ethernet communication infrastructure
- Capability or flexibility of upgrading legacy generator control systems
- Geographical location and climate of the site
- Necessary funding available to implement the balance of the project

All the existing and planned resources were evaluated and taken into consideration in the site selection process. A number of candidate sites were identified then evaluated against the criteria. A Pugh analysis was used to rank the sites quantitatively. Each criterion was first assigned a weight based on its importance to the technology and the demonstration. Each site was then compared against a chosen baseline/reference site. A weighted score was then calculated. The highest scores are the leading candidate sites. The end result was the selection of the AA-Substation at the MCAGCC at Twentynine Palms, California.

4.2 FACILITY/SITE CONDITIONS

Among the candidate sites considered, Twentynine Palms Marine Corps located in California ranked the highest and was selected as the site for the demonstration. Twentynine Palms had 7 acres of solar PV that total more than 1 MW, as well as a gas-fired cogeneration plant in excess of 7 MW. The base also had future plans for additional solar PV, fuel cells and advanced energy storage systems. The single line diagram of the Twentynine Palms power distribution system and a picture of the base are shown in Figure 4 and Figure 5. It is connected with the Southern California Edison utility grid at the Ocotillo substation. Some parts of the co-generation facility under Substation-AA will be used for demonstrating the microgrid.

Figure 2. Photo of Equipment Garages with Rooftop Solar Installations at MCAGCC at Twentynine Palms, CA Showing Pole Mounted 12.5kV AC Distribution Network.

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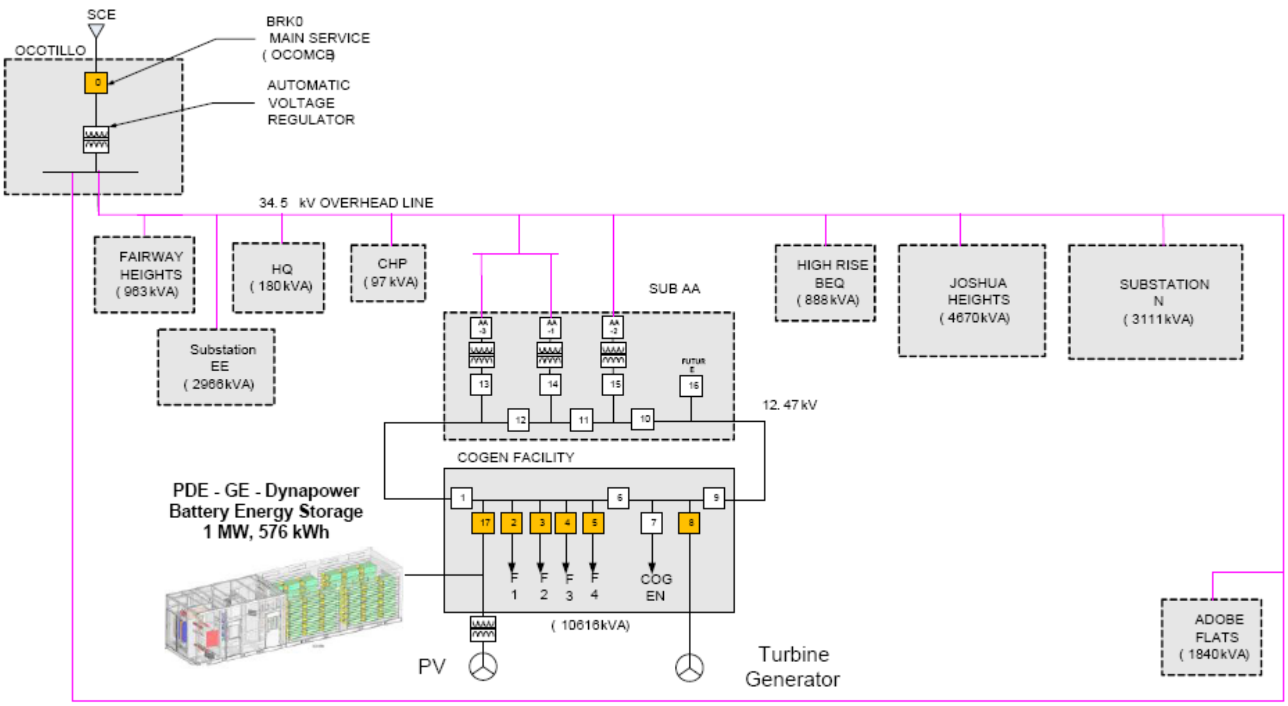

Figure 3. Twentynine Palms Marine Corps Site Electrical Single Line Diagram

Figure 4. Aerial View of MCAGCC Solar Field with BESS Location Indicated.

(Photo Google Earth, May 2012)

The selected site has an installed 7.2 MW gas turbine co-gen facility that supports base electric and high temperature hot water loads. It has diesel gensets and will have fuel cell systems on-site as well. It also had a 1MW solar PV system with plans to add additional MWs in coming years. The substations that power the base are being upgraded with automation equipment, smart meters, and sensor devices.

Following is the list of distributed generation assets available at the Base:

1) One combined heat and power unit (CHP) of 7.2MW capacity. Two more CHPs are being commissioned and will be ready by beginning of 2013.
2) One PV plant of 1MW rating. There are distributed PV modules all through the base (rooftops, parking lots etc.) which are currently not used in the energy management but are estimated to be about 2-3 MW total capacity.
3) Diesel gensets in about 35-40 buildings with a total capacity of around 4MW. However these units can be used only for emergency purpose and can't be used for regular microgrid operations due to environmental constraints from EPA.
4) A fuel cell unit, currently non-functional.

There are three main boilers available to provide the bulk of heating loads at the Base.

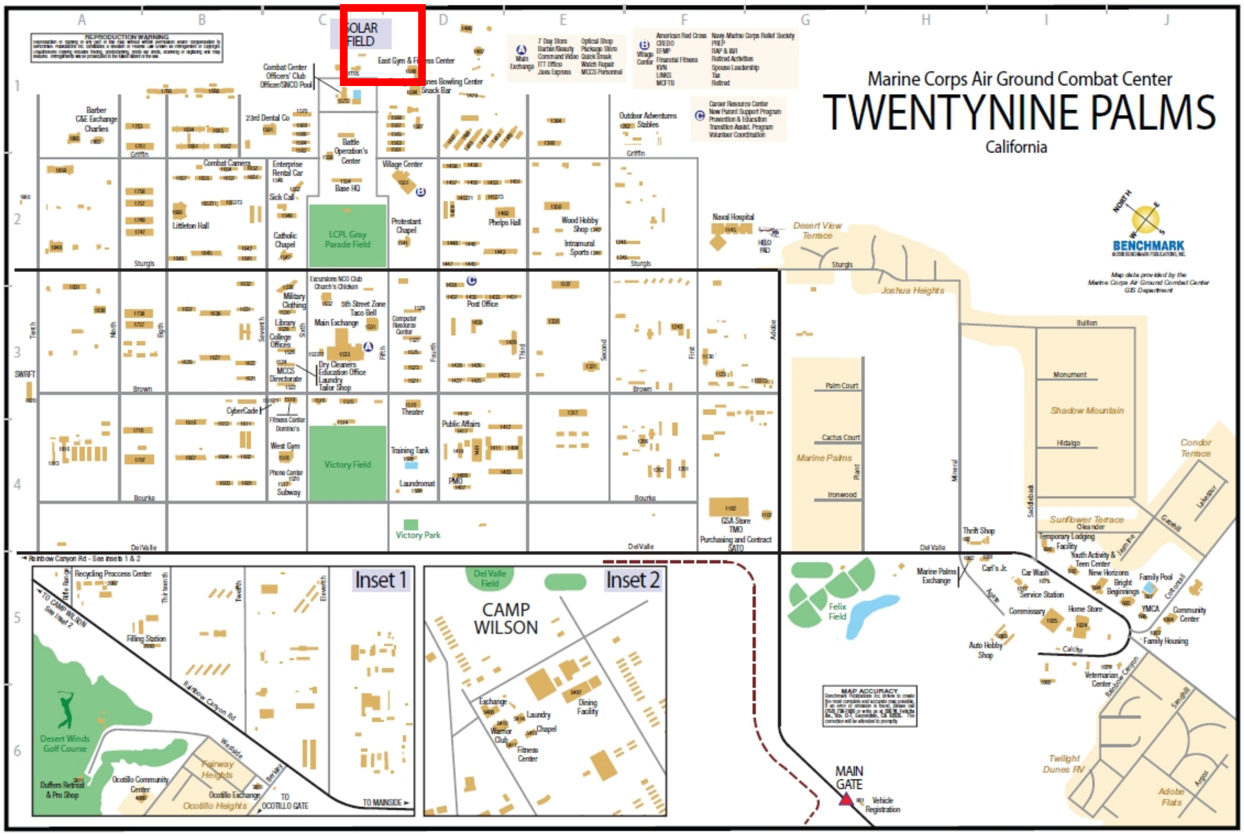

Figure 5. Map of the MCAGCC at Twentynine Palms Showing the Location of the 1MW Solar Field and the Location of the BESS.

5.0 TEST DESIGN

The fundamental problem addressed by this project and which this demonstration is intended to show improvement, is improved energy surety (renewable smoothing, in grid connected and island mode), and reduced energy costs (peak shaving, reduced demand charges). Heavy reliance upon imported power degrades energy surety, thus this project develops and field tests techniques to reduce reliance upon import power. Energy surety also improves as local power generation assets can be fully utilized and deliver power to more loads.

This demonstration was to assess how the BESS and dispatcher could effectively improve local generation efficiency and renewable energy integration. In addition, the demonstration was to provide data necessary to assess how well the technology could handle energy surety aspects both during grid-tied as well as islanded operation. The impact on the operator work load was also to be assessed.

Due to the experimental nature of the equipment and technology and the critical microgrid it is connected to, it is not recommended that onsite technicians conduct the demonstration.

The microgrid meets the optimum demonstration site criteria:

- PV provides intermittent renewables, the co-gen provides a conventional power source and the system ordinarily operates in grid-tied mode.
- Necessary microgrid metering is either in place or being installed as part of an ongoing system upgrade.
- The microgrid is generally a net power importer, but can seasonally be export power to other base loads. This provides a variety of conditions within which to demonstrate the technology.
- The GE microgrid control system project at Twentynine Palms Marine base applies well-established GE development frameworks and is designed such that it is easily extensible. The design also allows the operator to run the system in legacy, advisory or full-automatic mode. Additionally, each controllable asset can be selectively managed by the operator or the microgrid controller.
- A stated DoD goal is facility energy surety, so this proposal, by enhancing the

  Twentynine Palms Marine base benefits both the site as well as advancing overall DoD goals.
- The site offers severe environmental temperature extremes which will provide a solid proving ground for power electronic sand energy storage systems.
- In summary, the site power distribution system, the physical location and GE developed Microgrid control systems are optimal for demonstrating the proposed BESS technology and all parties in the demonstration benefit.

5.1 CONCEPTUAL TEST DESIGN

The project was to consist of three experiments. Only the first and second tests were done at the test facility at Dynapower. The third test was not completed due to termination of the Durathon™ battery platform:

- Prior to system final design, power quality and distribution system performance characteristics were quantified using historical data provided by the public works department. This included load and generation profiles of the system in grid-tied mode. It was determined that islanding of the microgrid was not feasible to take load and generation profiles. Based on these findings, the BESS system including the objectives of the control system were modeled and finalized.

  Dispatcher algorithms necessary for peak shaving and PV intermittency alleviation will be developed, modeled and tested onsite.

- A small-scale Dispatcher managed BESS system was tested using Microgrid “power import”, “power export” and “power neutral” scenarios during the factory testing at Dynapower. To the extent practical, these scenarios conform to system response and characteristics observed.

- The BESS system and enhanced microgrid controller will be deployed at Twentynine Palms Marine base and performance observed and analyzed against the models. The final experiment will include real-time monitoring and algorithm execution results on:

  1. PV array output
  2. Co-generation power and power factor
  3. Ramp rate control
  4. Sodium-Metal-Halide Battery Energy Storage for DoD Installations
  5. Grid power stability

5.2 BASELINE CHARACTERIZATION

Baselines will be required for all of the data mentioned in Section 5.1.

- Reference Conditions: The data that will be collected include:
  - PV power output, power factor and voltage.
  - Co-gen power output, power factor and voltage.
  - SCE power imported through Ocotillo, power factor and voltage.
  - Loads per feeder in the Co-gen switchyard (including load per phase).
  - Loads at each temporary building (including load per phase).
  - Performance data for each controllable microgrid asset (response times, states before and after the control event)
  - Operator performance data for operator-initiated events (response times, states before and after the control event).

- Baseline Collection Period: Some of the required data is collected regularly at the base. To the extent possible, this data will be used. Data that is not normally archived will be collected over a three month period.
- Existing Baseline Data:
  - PV power output, power factor and voltage.
  - Co-gen power output, power factor and voltage.
  - SCE power imported through Ocotillo, power factor and voltage.
  - Loads per feeder in the Co-gen switchyard. Per-phase load data is not available.
  - Transition to islanding standard operating procedure.
- Baseline Estimation: Baseline estimation will only be used to replace bad or missing data. In all cases, estimations will be based on other historical data. The algorithms used were developed at GE-Global Research using system data previously provided by Twentynine Palms.
- Data Collection Equipment: All data will originate either in the controllable asset, or in the associated relay. No specialized sensors will be needed.

System performance will be evaluated based on the reduction of energy consumption and grid reliability measurements. The project will enable and disable the MCS control functionality for the BESS unit to evaluate its effectiveness. Under Project EW-200937, historic energy cost data and reliability data will be collected for performance comparison with the BESS operation (day, week, month, & year).

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Describe the components and provide a depiction of the demonstrated system.

- System Design: The system was designed using a 1MVA bidirectional inverter with integrated transformer, a 250 kW/576kWh GE Durathon Battery spliced at 12.5kV to the existing PV feeder. The BESS was installed near the PV field approximated 2000’ from the substation “AA”. Reference figure 3 for electrical integration into the microgrid.
- System Depiction: Reference Figure 6
- Components of the System: Key components tested in the lab were the power conversion equipment, Durathon Battery, and GE microgrid controller.
- System Integration: The system was integrated to the existing circuit 7 in substation “AA”. The existing cable was spliced and a means of disconnect installed in order to isolate the BESS in the event of a failure. The microgrid controller was never integrated to the existing SCADA base system.
- System Controls: Reference Figure 8.

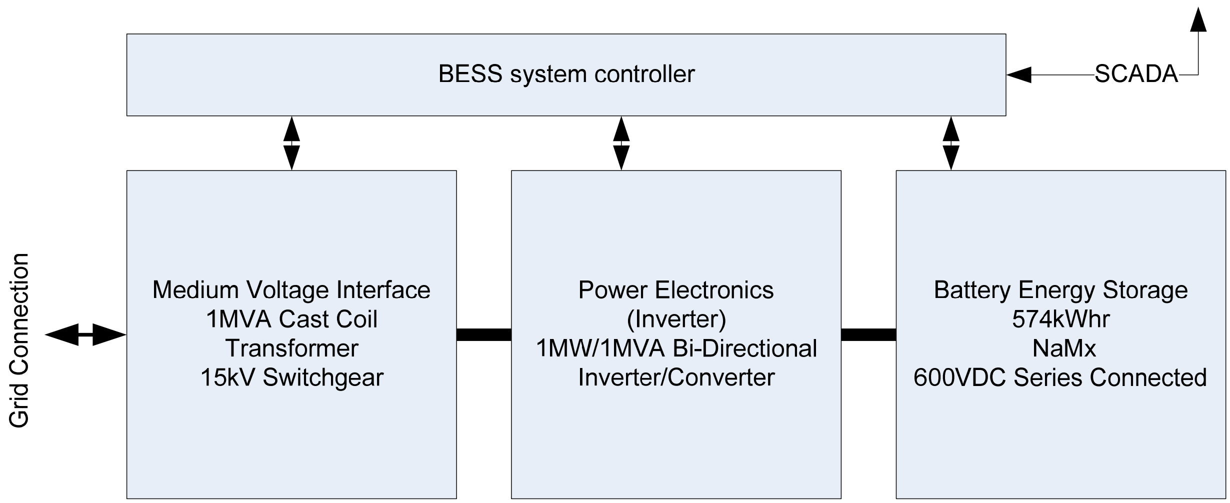

Figure 6. System Connection Block Diagram

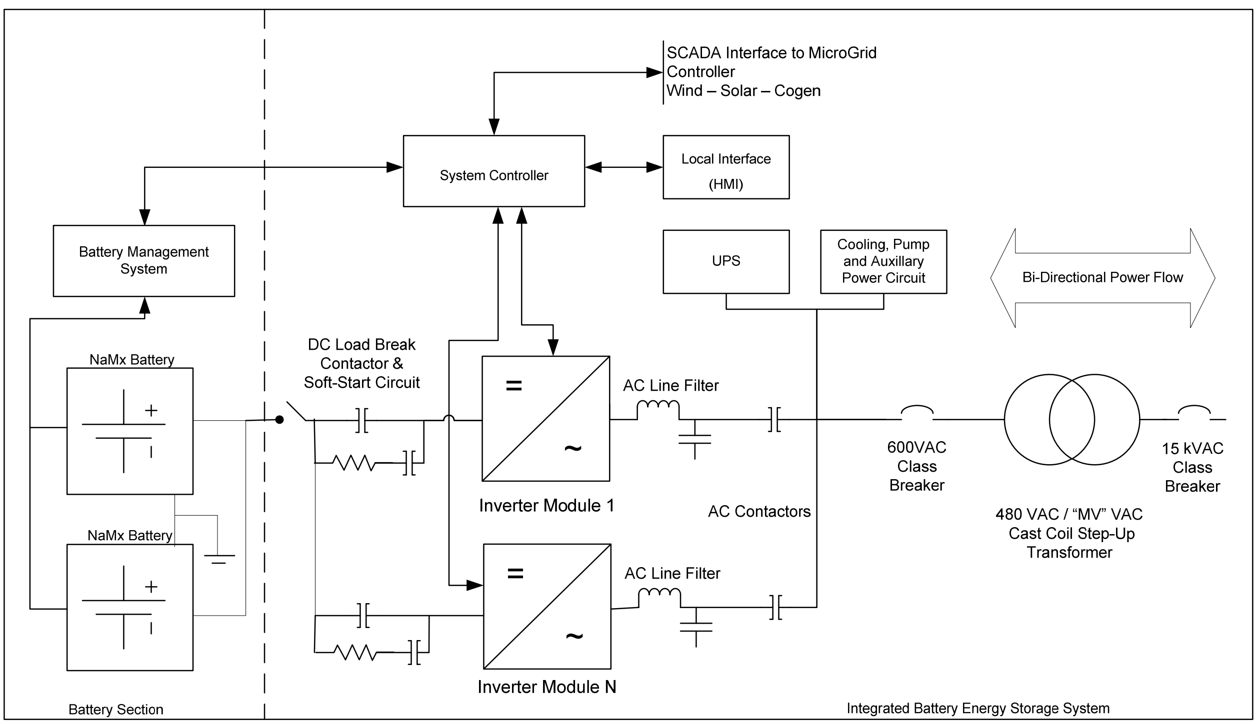

Figure 7. BESS Notional One-Line Diagram

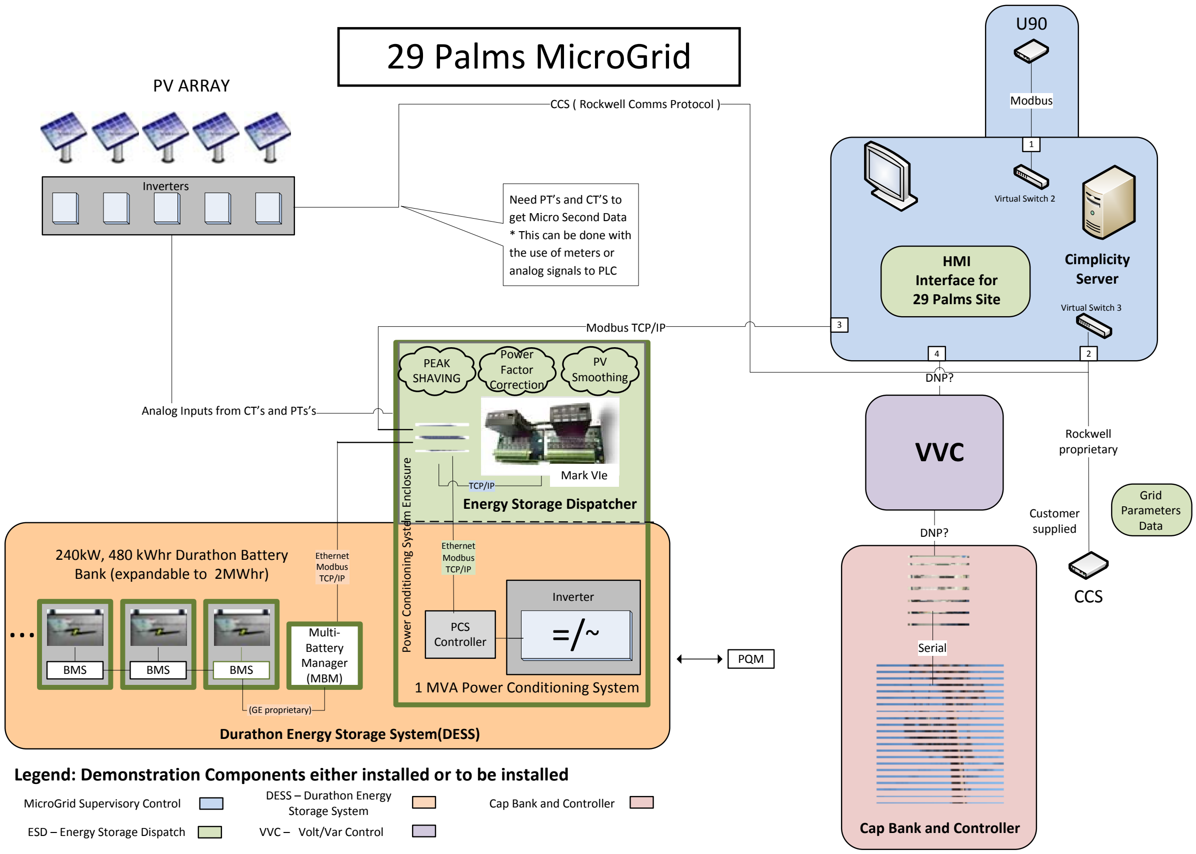

Figure 8. Controls Diagram

5.4 OPERATIONAL TESTING

Not Applicable

5.5 SAMPLING PROTOCOL

The sampling protocol was to result in the collection of relevant and sufficient data to validate the technology cost and performance under real-world conditions.

- Data Description: Data consisted of time-stamped Dispatcher state data and associated event and command-response logs.
- Data Collector(s): Data collection was built in to the Cimplicty™ environment. Human involvement was limited to test set up (as required) and error management.
- Data Recording: The automated data collection occurred over the testing period at the South Burlington VT integration testing.

- Data Storage and Backup: Initial data storage was on the ESX box. The ESX data store is configured as a RAID.
- Data Collection Diagram: Data originated at remote Microgrid devices. Their locations spanned the Microgrid, and all data flowed to the MCS. Figure 9 shows all data flowing to CIMPLICITY, then being passed on to the datastore.

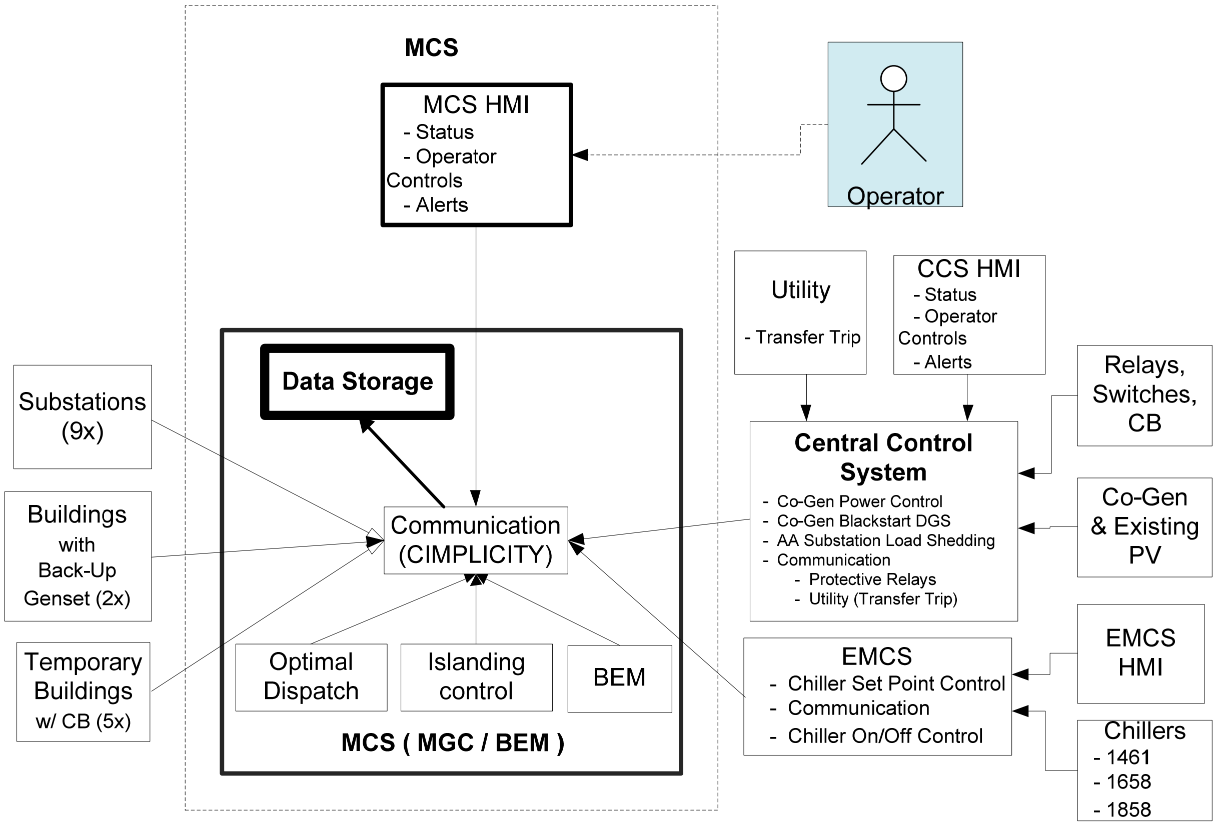

Figure 9. Flow Chart for Demonstration Data Acquisition

- Non-standard Data: None.
- Survey Questionnaires: There will be no formal surveys. At the close of testing, site personnel actively involved in MCS operation will be asked for comments and suggestions.

5.6 SAMPLING RESULTS

Testing at the base of operations was never executed. Only preliminary integration testing at Dynapower facility was taken.

6.0 PERFORMANCE ASSESSMENT

Minimal data analysis was applied to validate the performance objectives.

6.1 CO-GEN POWER FACTOR IMPROVEMENT

This objective was to improve the power factor of the CHP generator during normal grid-tied operations by supplying the reactive power from the BESS unit. The benefit of near unity power factor output from the generator is increased efficiency. **Appendix 9.2** shows that improving the power factor of the CHP generator will result in a 0.5% efficiency improvement, which results in a 35kW benefit. Unfortunately, the PCS which would supply the reactive power instead has a 2~2.5% inefficiency, and this would result in an equivalent amount of losses on the order of 30kW.

The analysis results show that the BESS reactive power support capability should not be used during steady state operations. Rather the team surmised that the strength of the BESS is its ability to quickly react to voltage disturbances, and it can help stabilize voltage response on the system in the transient state.

6.2 PEAK SHAVE FUNCTIONALITY

Data analysis of the base’s electric power consumption data showed that the peak load occurred on certain hours. Further analysis into the power purchase agreements showed that the MCAGCC base had no demand charges applied to their electricity use, so there was no incentive to reduce peak electric power consumption.

See **Appendix 9.3** for a Plot of Peak Power vs. Low Peak Hours.

6.3 RENEWABLE ENERGY SMOOTHING 1 (GRID TIED)

The objective of this test was to smooth the output of the renewable energy sources in order to reduce any ill impact on voltage quality. This test objective was to precede any grid independent mode testing where the value of renewable smoothing is more tangible and beneficial.

The real power output of the PV field was monitored and an example power trace with high variation (cloud bursts) was used for the Renewable Energy Smoothing tests at Burlington Vermont. Two types of smother were applied, a) moving average of the PV real power production, and b) daily average PV output smoothing (flat line). The test results are shown in the Appendix.

6.4 RENEWABLE ENERGY SMOOTHING 2 (GRID INDEPENDENT)

Similar to grid tie mode when grid is operating in an independent islanded mode.

6.5 DURATHON BATTERY BANK AVAILABILITY

No specific data was collected for this performance objective.

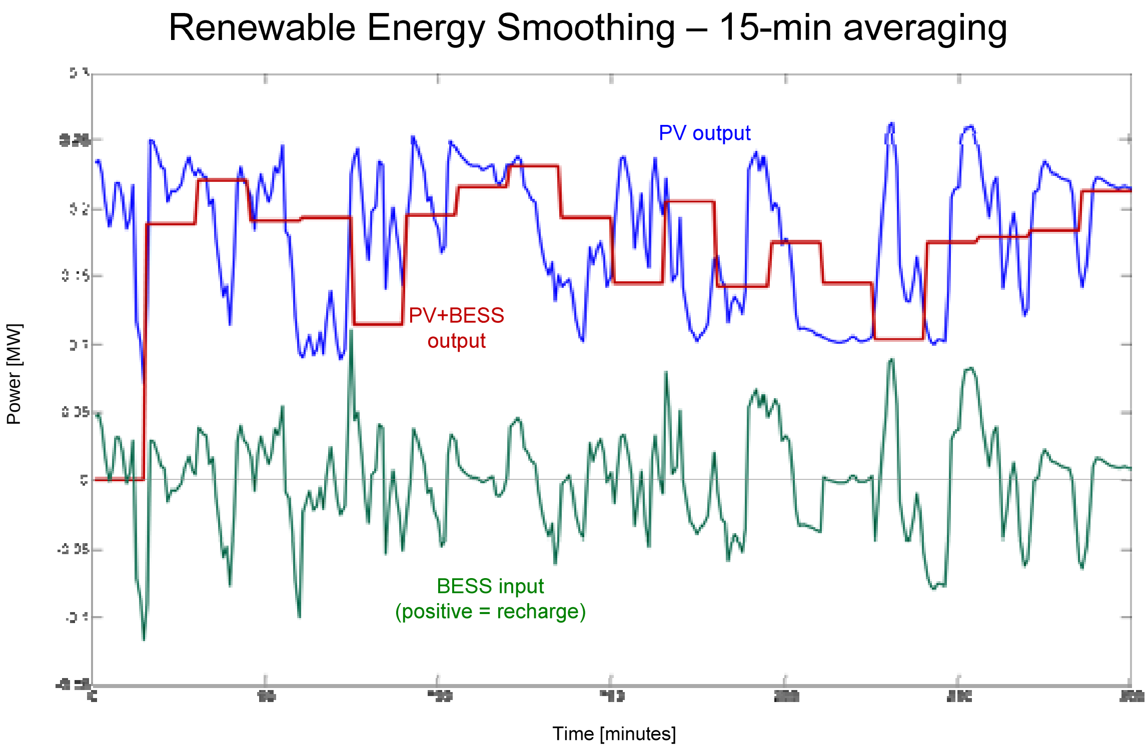

Figure 10. Power vs. Time of BESS Smoothing Based Upon 15-min Averaging of the PV Output.

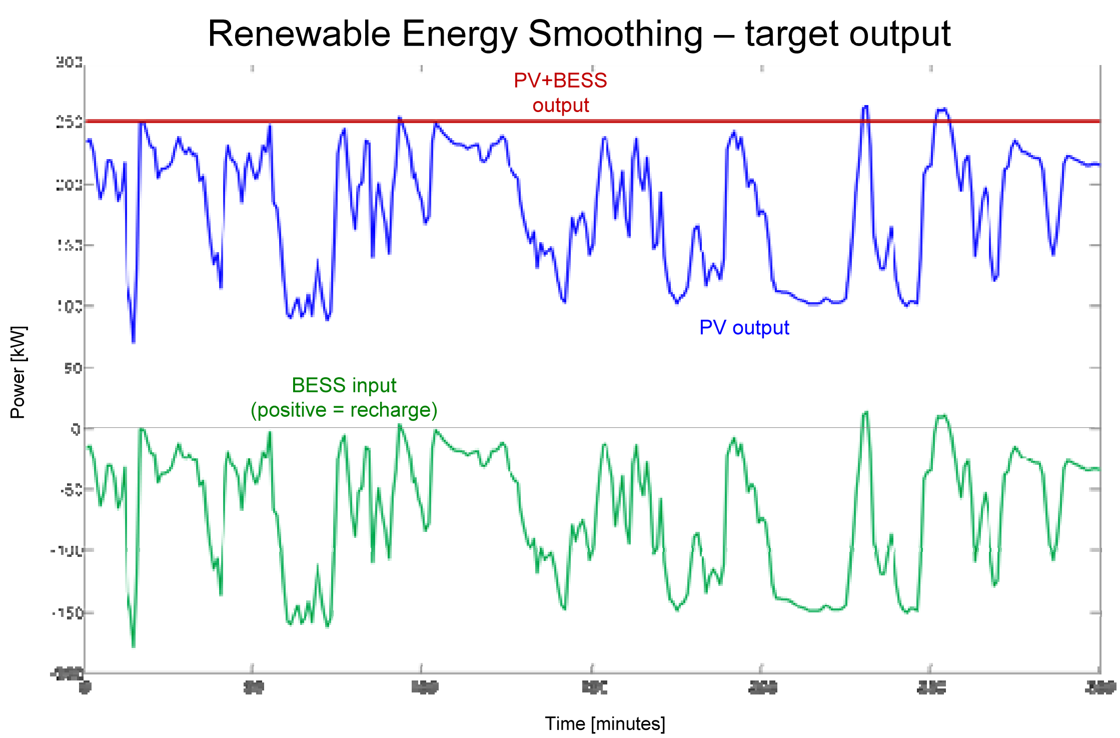

Figure 11. Power vs. Time of BESS Smoothing Based Upon 4-second Response to a Pre-defined Target Power (250kW)

7.0 COST ASSESSMENT

This technology is no longer commercially available and a basis of cost assessment cannot be determined.

7.1 COST MODEL

Table 3. Cost Model for an Energy Efficiency Technology

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	Estimates made based on component costs for demonstration	GE Durathon™ battery 1000 $/kWh. Inverter cost was .52/watt.
Installation costs	Labor and material required to install	$200/kWh
Consumables	Inverter filters	1,400/yr.
Facility operational costs	Reduction in energy required vs. baseline data	Tar losses associated with the inverter approximately $500/yr.
Inverter Maintenance	• Annual electrical testing and filter change out • Rebuild at year 10	$6,000/year $25,000
Hardware lifetime	Estimate based on components degradation during demonstration	10 year lifetime on components
Operator training	Estimate of training costs	$10,000 at commissioning

[1] Detailed list of materials and analytical costs provided in Final Report

A cost model was not formally produced for this prototype BESS but the below elements are provided for clarity and historical documentation.

H/W Capital Costs

- The GE Durathon™ battery technology is no longer being offered, but was available at an initial capital costs of 1000 $/kWh at the time of the award. Later generations of the battery modules were offered at lower prices for higher volume purchases, on the order of 500 $/kWh. The technology never achieved the projected price floor of 200 $/kWh.
- The PCS system, as offered by Dynapower in the form of a PowerSkid™, was available at a capital cost of 300 $/kW at the time of award. More recent pricing for simplified product offerings are in the range of 80-120 $/kW.
- The Controls and Dispatch functionality usually has a fixed cost of 10,000 to 50,000 $.

Installation Costs

The installation costs vary from site to site and may also include engineering drawings, application fees, interconnect fees, which sum to an amount as high as $250,000 for a single installation. Today's cost are typically around $250/kWh if existing electrical infrastructure is in place and sized to accommodate the BESS.

Consumables

BESS systems have consumables, such as air filters, wear out parts like switching modules, and battery components. Estimated cost for consumables is $1,400/yr. for inverter parts. Batteries have no planned consumables.

Facility Operation Costs

BESS equipment do not have any special facility operation costs. Very low TAR losses could be expected from the inverter being online during non-solar producing hours.

Maintenance

The BESS systems as installed had very low maintenance costs, only requiring annual inspections and consumable (worn parts) replacements. It is estimated that the annual maintenance costs are $6,000/year and a $25,000 inverter rebuild at year 10.

Hardware Lifetime

The BESS as designed had a 10 year expected lifetime, with possibility to extend to 15 years via maintenance contracts.

Operator Training

BESS units generally have very low operator training as they are fully automated devices which work off software with programmed objectives. Typical military project training costs are approximately $10,000 for a week of onsite training with the manufacturers' representatives' onsite.

7.2 COST DRIVERS

The key cost drivers for BESS systems is the battery pricing. Over the timeframe of this contract the battery energy storage pricing fell almost by 50% for Li-Ion systems, but only 25% for Sodium Metal Halide systems.

A secondary value driver for BESS systems is the cycle and calendar life of the assets. Over the timeframe of this contract, the projected battery life doubled for Li-Ion systems, but only improved by 20% for Sodium Metal Halide systems.

7.3 COST ANALYSIS AND COMPARISON

A life cycle cost analysis for the BESS design was not done on this project. But many life cycle cost analyses exist for energy storage. A popular one that is well accepted in industry is Lazard's Levelized Cost of Storage Analysis. The LCOE assessments were applied to various applications, such as short term frequency regulation, as well as renewable firming, and peak shifting. The analysis also has pricing trends that extend to 2020.[2]

[2] https://www.lazard.com/media/2391/lazards-levelized-cost-of-storage-analysis-10.pdf

IMPLEMENTATION ISSUES

As the Marine Corps' leading exercise training facility, the base was tying together its disparate electrical infrastructure in a more optimal way while serving as a test bed for new technologies through various DoD initiatives including the Environmental Security Technology Certification Program (ESTCP).

Lessons learned on the project:

- Competing 115kV substation and new co-generation projects took priority over (ESTCP) BESS project causing delays. ESTCP did not have the authority to overturn this decision.
- Although this project originally was to island the microgrid and perform testing it became apparent that the approvals and desire by the base to perform this test was not feasible.
- Li-Ion battery technology quickly became the market preference for both price and performance.
- With today's completely integrated modular systems from multiple manufacturers it is recommended to select a standard offering from a reputable company utilizing Li-Ion technology.

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8.0 REFERENCES

1. EW 201147 Fact Sheet from the ESTCP website: https://www.serdp-estcp.org/Program-Areas/Energy-and-Water/Energy/Microgrids-and-Storage/EW-201147

2. Dynapower Quality Procedure # SOP 7.6.001 Rev. 5 Control of Monitoring and Measuring Equipment

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name Address	Phone Fax Email	Role in Project
Dan Cohee	PDE Total Energy Solutions 9970 Bell Ranch Drive #109 Santa Fe Springs, CA 90670	562-824-0834 562-204-3550 dcohee@pdeinc.com	Principal Investigator
Herman L.N. Wiegman, Ph.D.	GE Global Research 1 Research Cir., K1-4C33 Schenectady, NY 12345	tel: 518-387-7527 tel: 518-385-7507 cell: 518-813-6577 wiegman@ge.com http://www.ge.com/research/	Technical lead

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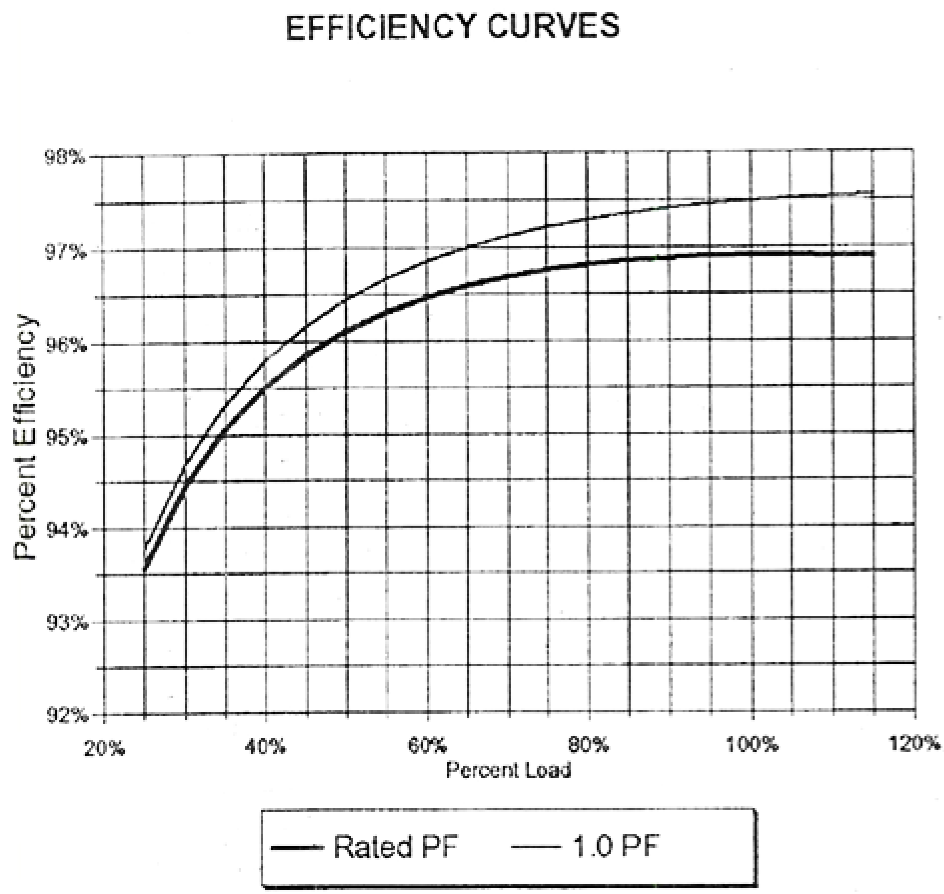
APPENDIX B CHP GENERATOR EFFICIENCY FOR TWO POWER FACTORS



100% Load = 7200 kW

Class B Temperature Rise

Rating:
9000 KVA
12470 Volts
417 Amps
0.80 P.F.
1800 RPM

Generator is 9MVA rated, and interfaces with the 12.47 kVac system.

Improving the power factor from 0.8 to 1.0 will yield a 0.5% efficiency improvement.

This represents 35kW of additional power for distribution, which results in $18k per year of additional savings (assuming 8760 hrs/year use and 0.06 $/kWh energy purchase price)

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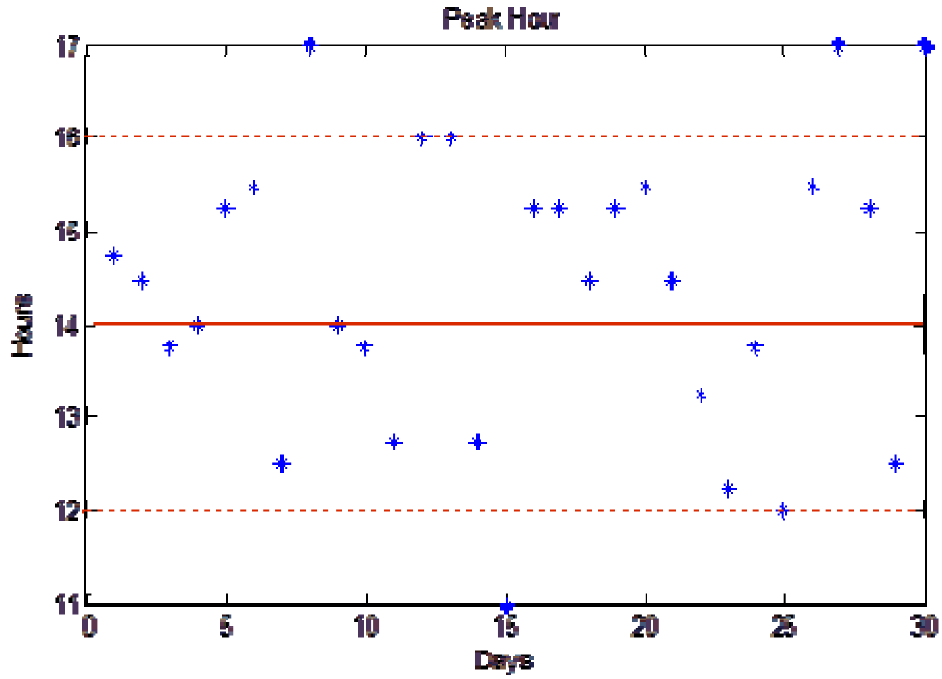
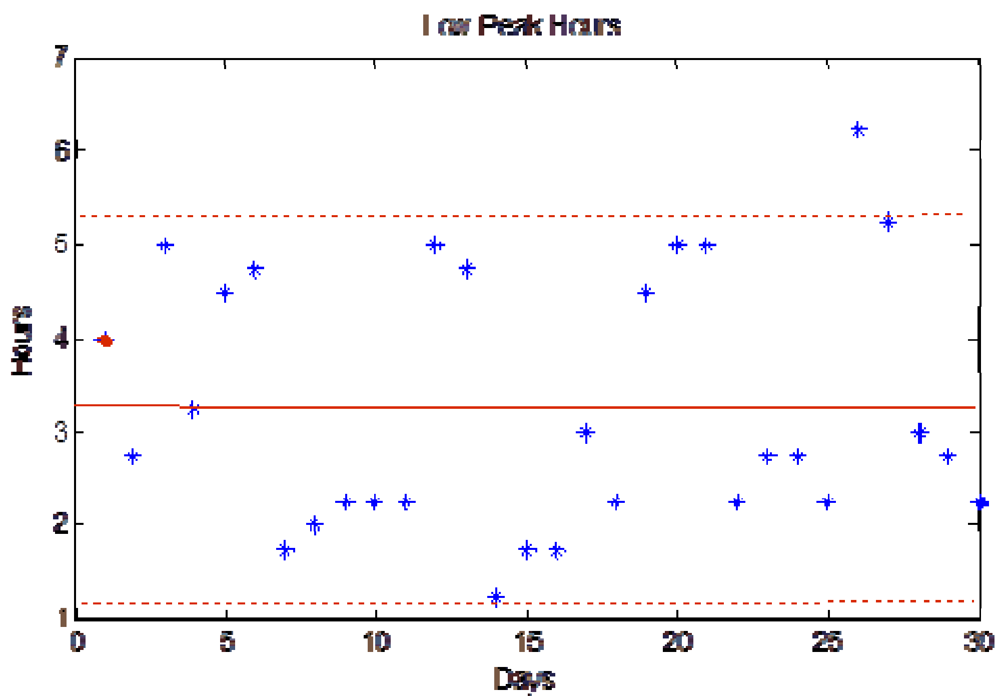
APPENDIX C PEAK HOUR VS. LOW PEAK HOURS





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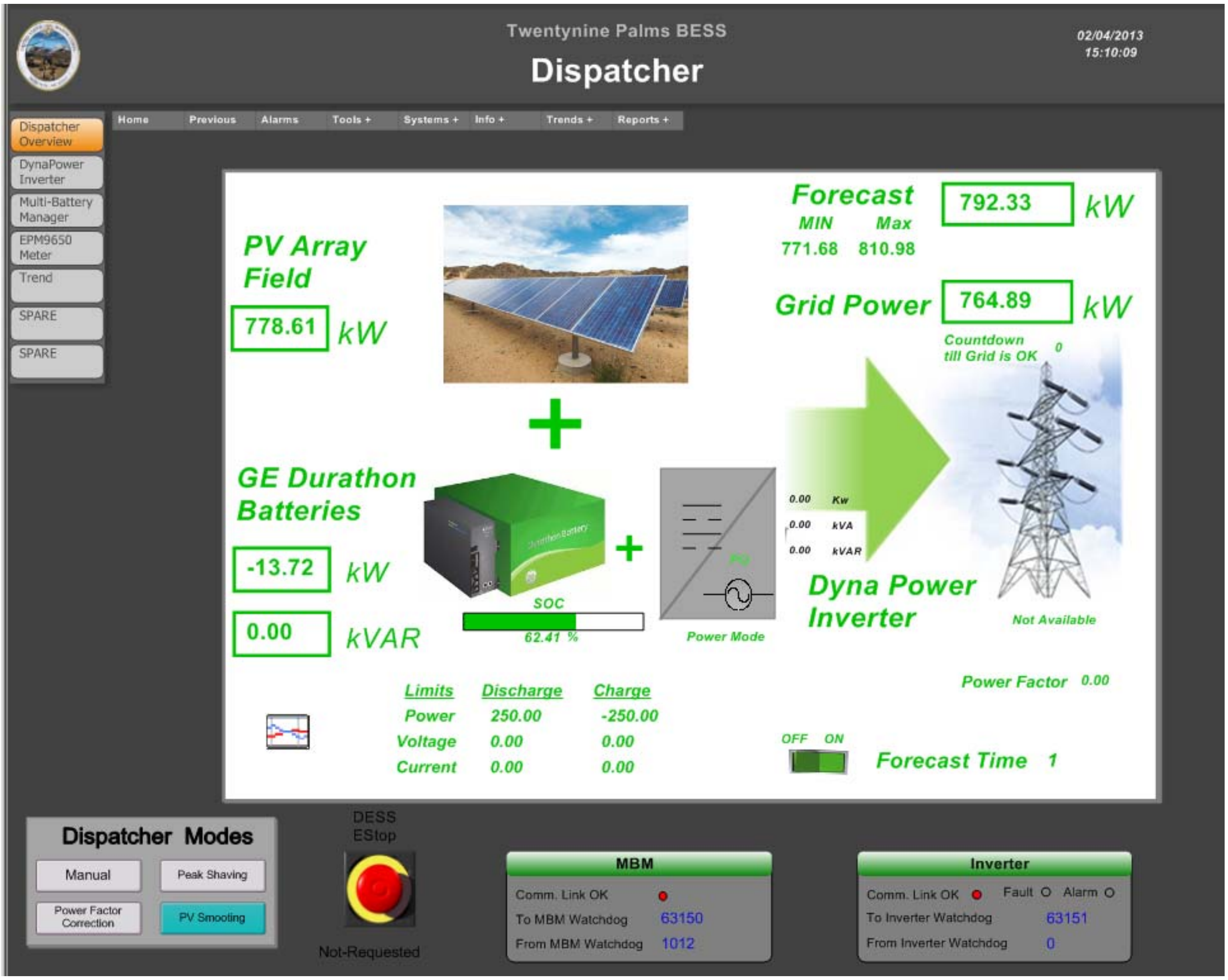
APPENDIX D CIMPLICTY HMI SCREEN



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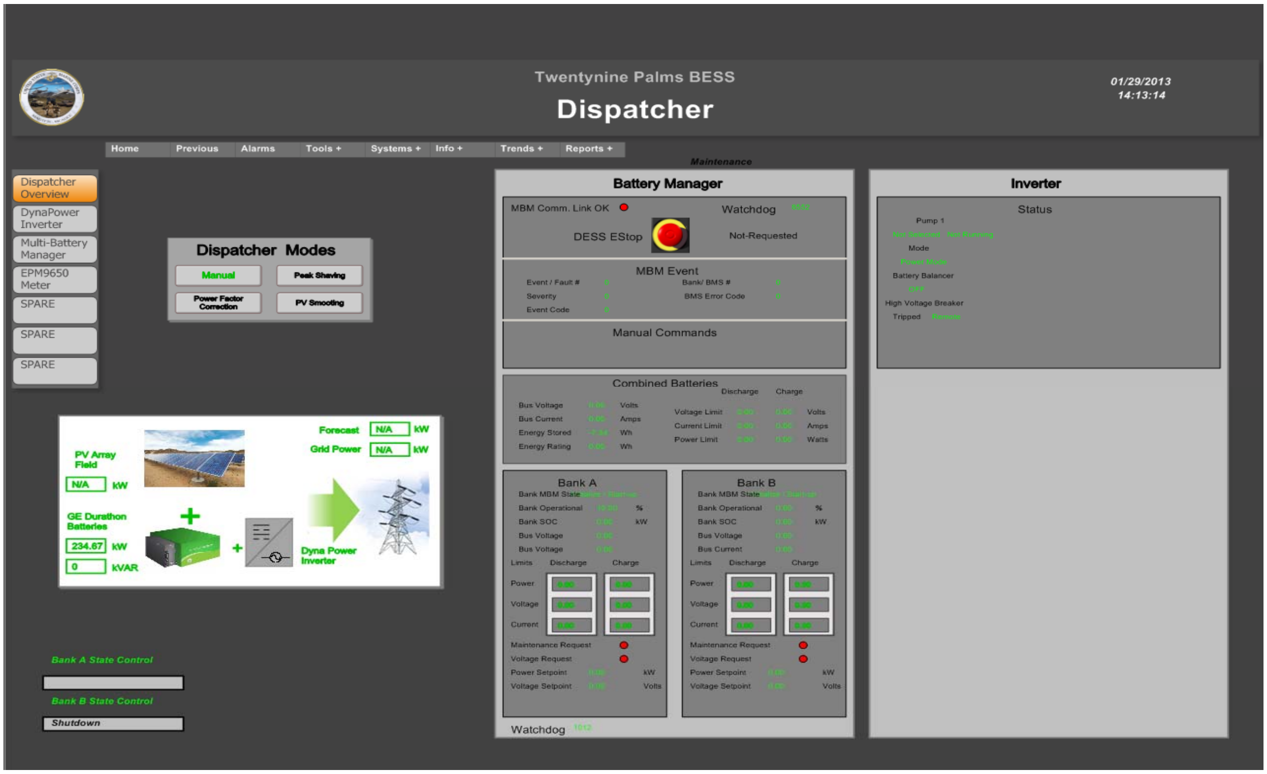
APPENDIX E DISPATCHER SCREEN



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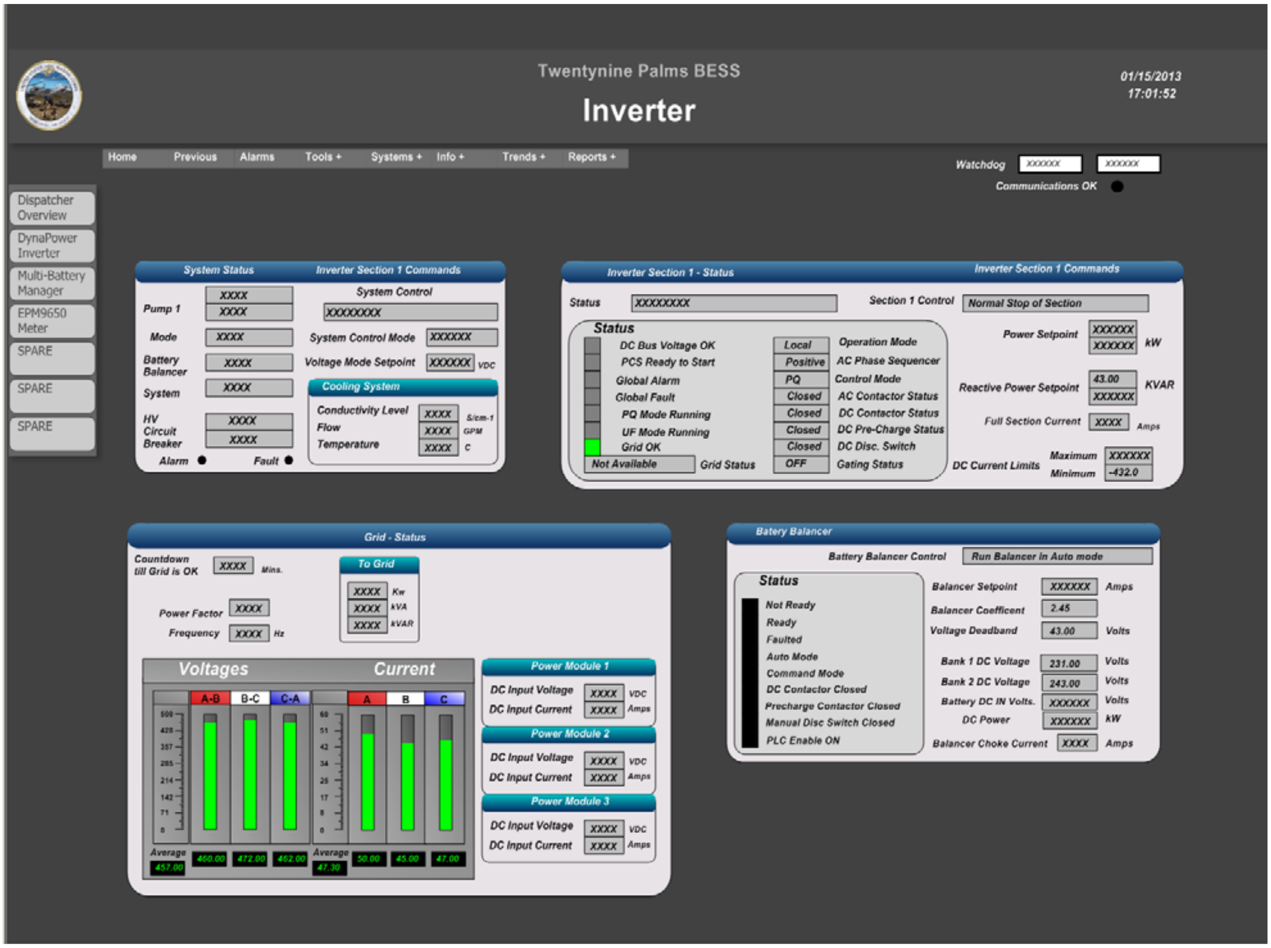
APPENDIX F INVERTER VIEW



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APPENDIX G ELECTRICAL DRAWINGS